AD-A136 136 INTERFEROMETRY OF MOVING OBJECTS UNDER WATER(U) ARIZONA UNIV TUCSON OPTICAL SCIENCES CENTER F A HOPF NOV 83 N00014-81-K-0754 1/1

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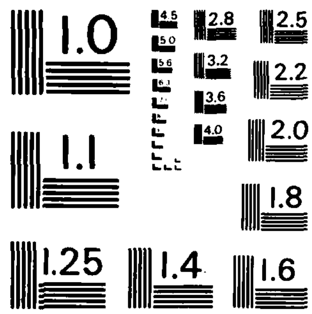

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Final Report on Contract N00014-81-K-[redacted]

INTERFEROMETRY OF MOVING OBJECTS UNDER WATER

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November 1983

Final Report for Period 1-1-81/7-15-83

Approved for public release;
distribution unlimited.

Prepared for
Office of Naval Research
800 North Quincy Street
Arlington VA 22217

UNCLASSIFIED
SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION: Unclassified	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION/AVAILABILITY OF REPORT: Approved for public release; distribution unlimited.
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S)	5. MONITORING ORGANIZATION REPORT NUMBER(S)
6a. NAME OF PERFORMING ORGANIZATION: Optical Sciences Center; 6b. OFFICE SYMBOL (If applicable)	7a. NAME OF MONITORING ORGANIZATION: Office of Naval Research
6c. ADDRESS (City, State and ZIP Code): Optical Sciences Center, University of Arizona, Tucson, AZ 85721	7b. ADDRESS (City, State and ZIP Code): 800 North Quincy Street, Arlington VA 22219
8a. NAME OF FUNDING/SPONSORING ORGANIZATION: Office of Naval Research; 8b. OFFICE SYMBOL (If applicable)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER: N00014-81-K-0291
8c. ADDRESS (City, State and ZIP Code): 800 North Quincy Street, Arlington VA 22219	10. SOURCE OF FUNDING NOS.: PROGRAM ELEMENT NO. / PROJECT NO. / TASK NO. / WORK UNIT NO.
11. TITLE (Include Security Classification): Interferometry of Moving Objects under Water	

12. PERSONAL AUTHOR(S): F. A. Hopf

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Yr., Mo., Day)	15. PAGE COUNT
Final	FROM 1-1-81 TO 7-15-83	11-30-83	4

16. SUPPLEMENTARY NOTATION

17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB. GR.	

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

It has been demonstrated that interferometers using nonlinear optics are suitable for the task of examining underwater surface deformations that are much larger than optical wavelengths. The demonstration has been limited to 1.06-μm devices whose sensitivity is of the order of 100 μm. The precise sensitivity is somewhat adjustable by examining the object in transmission rather than reflection. The device has been operated under simulated field conditions, and has proved to be insensitive to high levels of vibration. The attempt to make a more sensitive device operating at 0.69 μm has not been successful.

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT: UNCLASSIFIED/UNLIMITED ☒ SAME AS RPT ☐ DTIC USERS ☐	21. ABSTRACT SECURITY CLASSIFICATION: Unclassified
22a. NAME OF RESPONSIBLE INDIVIDUAL	22b. TELEPHONE NUMBER (Include Area Code); 22c. OFFICE SYMBOL

DD FORM 1473, 83 APR — EDITION OF 1 JAN 73 IS OBSOLETE.

Unclassified
SECURITY CLASSIFICATION OF THIS PAGE

I. SUMMARY OF OBJECTIVES

The purpose of this contract was to develop common path interferometers based on nonlinear optical techniques for observing deformations on plastisol surfaces being tested at NOSC for drag reduction. As a necessary by-product of this task, the principal investigator acted as a consultant to NOSC to make preliminary estimates of the sizes of the deformations. The deformations of interest are the streamwise ripples observed on the surface at Reynold's numbers that exceed the critical Reynold's number for turbulent flow. Static divergences that appear at a higher Reynold's number were used to demonstrate the capability of the interferometer.

II. NONLINEAR OPTICAL INTERFEROMETERS

The basic idea of a nonlinear optical interferometer is to utilize the co-propagating properties of laser and second harmonic light beams. These beams experience different phase lags due to differential dispersion in a medium. This phenomenon can be exploited to give an interference pattern by subsequent doubling of the laser light, which reproduces the phase front of the laser beam but at the higher frequency. The interferometer has an effective wavelength of $\lambda/\delta n$, where δn is the dispersion and λ is the wavelength. The effective wavelength can be hundreds of optical wavelengths long, since $\delta n \sim 0.01$.

Any interferometer that is testing an object of uncontrolled, time-varying optical figure must have an effective wavelength that is comparable to the size of the distortion; otherwise the fringes show either no motion or too much motion. This explains the consultant aspect of the effort, insofar as the distortion size and therefore the design of the interferometer remained unknown throughout the duration of the contract. The only practical method of changing the sensitivity of a nonlinear interferometer is to operate at different wavelengths. This is a major difficulty since convenient nonlinear optical materials exist only at 1.06 μm.

III. PRELIMINARY TESTS

Since the design goals and the instrument test were under simultaneous development from the beginning, it was desirable to obtain preliminary data as quickly as possible. Accordingly, the principal investigator suggested a laser scattering test that has been implemented in the flow tank ever since. The initial test was done by the principal investigator, and from the beginning it was clear that there were major discrepancies between the preliminary estimates in the depth of the deformations ($\sim$ 100 μm) and the data ($\sim$ 0.5 μm). Efforts were made by NOSC to alter the depth by changing material composition, but it was found that the deformation size is not readily varied. These facts are clear now, but were not at the time of the research. The reason for concern is that such a deformation is too small to be seen by any common path interferometer except shearing interferometers; these give slope information, which is already obtained from the scattering experiment. Dual beam interferometers are impractical due to the optically hostile character of the experiment.

IV. TESTS OF THE NONLINEAR INTERFEROMETER

The goal of the test of the nonlinear optical interferometer was to demonstrate the capability of observing deformations under conditions that simulated the real test. A test bed used for testing propellers was borrowed from NOSC and was modified for the interferometer. The optical bench on which the interferometer was mounted was the 0.25-in. steel base of the tank; the same structure onto which the driving motor was bolted. This realistically simulated the flimsy mounting structure and high vibrations that would be encountered in the NOSC flow tank. The test involved spinning the test object on the propeller shaft. The first object tested was a spun optical flat. Straight fringes were

observed which demonstrated that there were no spurious sources of fringe distortion.

Tests of the plastisol disks were generally difficult due to a rapid deterioration of the surface reflectivity. This deterioration has not been observed elsewhere, and the causes remain unknown. The object was finally tested in transmission by mounting a mirror behind the plastisol. The light thus made two passes through the object, causing twice the amount of distortion. The static divergences were readily observable in the fringe pattern, hence the test demonstrated the capability of the device to obtain quantitative information about the surface structure. It also proved that the device is capable of performing measurements in adverse environments.

V. RUBY INTERFEROMETER

The preliminary tests showed that, in principle, the interferometer was well suited to the task. It was also clear that, even with the added sensitivity of the double pass setup, the distortions were much too small to be observed at 1.06 μm. It still seemed possible at the time that the distortions might be made small enough so that an interferometer at 0.69 μm might be sensitive enough. Preliminary measurements showed that the plastisol is transparent at the second harmonic of ruby. It was decided to try to make a version of the interferometer at this wavelength. A laser was available at NOSC to carry out the preliminary tests, which were designed to demonstrate that such an interferometer could be built, and to use it to measure the dispersion of the plastisol. The experiments were carried out at NOSC, using designs provided by the principal investigator. There was one element of high risk in this effort, namely that we were unable to find a supplier who would provide the needed nonlinear crystal either at tolerable cost, or with any assurance that it would work. We decided to try an autocorrelator crystal, which has properties that are nominally suited to the task.

The device was built and was tested at NOSC. Due to breakdowns in the laser, these tests were prolonged over several visits of the principal investigator. At the end, it was clear that the device was not working as expected, and as of this date we do not know why. All elements of the device seem to meet expectation, and we have solved all problems of detection, etc., that are a major difficulty with any of these tests. We have not, however, been able to observe fringes in our test objects, even in cases in which we know that they are observable. At the time this work was in progress, experiments in the flow tank were confirming repeatedly that the initial estimates of very small distortions were true. Even with the most optimistic estimates of the sensitivity of the ruby device, it cannot be made sensitive to 0.5-μm disturbances. Hence it was decided to abandon the effort to develop the device.

VI. CONCLUSIONS

In conclusion, it has been demonstrated that interferometers using nonlinear optics are suitable for the task of examining underwater surface deformations that are much larger than optical wavelengths. The demonstration has been limited to 1.06-μm devices whose sensitivity is of the order of 100 μm. The precise sensitivity is somewhat adjustable by examining the object in transmission rather than reflection. The device has been operated under simulated field conditions, and has proved to be insensitive to high levels of vibration. The attempt to make a more sensitive device operating at 0.69 μm has not been successful. Plastisol objects are transparent at the second harmonic of the ruby laser, so there are no fundamental obstacles to making the device work. We are unable to explain the failure. However, it is clear that the deformations of interest to NOSC are so small that it is extremely unlikely that the ruby device will be of value. It has been decided to abandon the project until such time as further development is warranted by applications.